

## STORAGE OF TRUCK CROPS: THE GIRASOLE, *HELIANTHUS TUBEROSUS*<sup>\*1</sup>

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(WITH FOUR FIGURES)

The girasole,<sup>3</sup> *Helianthus tuberosus*, has had much interest centered upon it since the report of JACKSON, SILSBEE and PROFFITT (4) on the possible commercial preparation from it of fructose, a sugar sweeter than sucrose, according to PAUL (7), DEERR (3), SALE and SKINNER (8), BIESTER, WOOD and WAHLIN (2) and SPENGLER and TRAEGL (10). A survey of the plants which might serve as a source for the commercial production of fructose shows that the girasole ranks among the more promising. The plant has been in general use in many European countries for a long time as a truck crop and as a stock food, and to a lesser extent this is true for certain sections of the United States.

One of the chief problems in connection with this crop is that of storage. The periderm of the girasole tuber is very thin and easily ruptured. There is a rapid loss of moisture on exposure to atmosphere at room temperature. The tubers are subject to parasitic diseases under ordinary storage conditions.<sup>4</sup> Most authorities seem to be agreed that the best method of storage is the practice of leaving the tubers in the ground and digging them when needed. SHOEMAKER (9) reports good success with tubers stored in burlap bags in a cold cellar at Washington, D. C., from November, 1925, to March, 1926, without shriveling or other difficulty. The temperature was kept near the freezing point. The preliminary experiments reported in this paper covering the period from August 30, 1927, to March 22, 1928, were carried out in order to secure more accurate information with regard to the storage of this crop.

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<sup>3</sup> *Helianthus tuberosus* is not an artichoke and is not native to Palestine; therefore, "Jerusalem artichoke" is a lengthy misnomer, and is being replaced, for purposes of economy, if for no other reason, by the simpler term, "girasole." See L. H. BAILEY, Vegetable Gardening, 1890.

<sup>4</sup> A study of the diseases of girasole tubers in storage was carried on parallel with the experiments reported in this paper by Prof. H. W. JOHNSON, of the Division of Plant Pathology. This report will be published separately.

### Methods

The general plan of the experiment included the study of the dry matter and water soluble carbohydrates in the tubers of the Portland variety from August 30, 1927 to March 22, 1928, (1) outdoors on silt loam, (2) outdoors on sandy loam, (3) in common storage at 34°–49.5° F., (4) common storage at 33.5°–44° F., (5) in cold storage at 32°–35° F. The tubers were washed, dried with a towel and ground to a pulp in a food chopper. The pulp was thoroughly mixed, after which 100 gm. were taken for a moisture determination, and two 30-gm. portions for sugar analysis. Fifteen cc. of water were added to each of the 30-gm. samples in a 250-cc. beaker and the mixture was set in a boiling water bath for one hour. The extract was pressed from the pulp while hot, with a small juice press, into a 100-cc. volumetric flask. The pulp was washed with two 15-cc. portions of boiling water, the washings being added to the first extract. The combined extracts were hydrolyzed with 2.5 cc. of 8.12 N HCl on a water bath at 70–80° C., for 35 minutes and cooled to room temperature. To clarify the hydrolyzed extract, solid neutral lead acetate was added until precipitation was complete. A white precipitate of lead chloride is deposited first and this is followed by colloidal matter. The mixture was then diluted to volume (100 cc.) and filtered, delead with solid disodium phosphate and filtered again.

Aliquots of the delead filtrate, which was clear and practically colorless, were used for the selective determination of fructose and total reducing substances by OST's cupro-carbonate method as modified by NYNS (5). The cupro-carbonate solution was prepared as follows: 250 gm.  $K_2CO_3$  and 100 gm.  $KHCO_3$  were dissolved in 700 cc. boiling water; 25.3 gm. of very pure  $CuSO_4 \cdot 5H_2O$  dissolved in about 100 cc. of water were added, and the solution was made up to 1 liter. One or 2-cc. aliquots of the clarified sugar solution were placed in 250-cc. Erlenmeyer flasks and distilled water was added to make a total of 20 cc. Then 50 cc. of cupro-carbonate solution were added and the mixture was reduced: one set on a water bath kept at 48.5–49° C. for the determination of fructose, and another set on a boiling water bath for the determination of total water soluble carbohydrates. Reduction was carried out for exactly 2.5 hours, when the cuprous oxide precipitates were collected in Gooch crucibles on asbestos mats. The amount of copper was determined in each case by the permanganate method as given in Official Methods (1). These values, referred to tables in OLIVER's paper (6), gave the amount of fructose and of total reducing sugars. Subtracting the former from the latter gave "glucose," a term here used to include glucose and any other reducing substances other than fructose which may be present.

### Kinds of carbohydrates present

In an attempt to determine the amount of free reducing sugars in the girasole tuber, a sample (Nov. 3, 1927) was extracted in the usual way, except that some  $\text{CaCO}_3$  was added to prevent hydrolysis of polysaccharides by the natural acidity of the juice. Hydrolysis with  $\text{HCl}$  was omitted but the extract was clarified with neutral lead acetate and delead as usual. This unhydrolyzed extract was subjected to the cupro-carbonate reduction at  $48.5\text{--}49^\circ \text{C.}$ , and at  $100^\circ \text{C.}$  In both cases no more copper was reduced than in the case of the blank for the method, indicating the absence of free fructose or free "glucose."

Samples of the same material were extracted at room temperature ( $23^\circ \text{C.}$ ) instead of at  $100^\circ$  and in the presence of  $\text{CaCO}_3$  to prevent hydrolysis. In this case the extract was also filtered to remove  $\text{CaCO}_3$  particles. The extract was then hydrolyzed with  $\text{HCl}$  and run through the usual procedure. In this way it was hoped to remove the water soluble levulins or inulides without removing inulin itself. However, the analyses gave only slightly lower values for fructose and "glucose" in this extract than in the case of the extracts prepared in the usual way.

	Fructose <i>per cent.</i>	"Glucose" <i>per cent.</i>
Usual method .....	10.90	5.71
Cold extraction in presence of $\text{CaCO}_3$ and hydrolysis with $\text{HCl}$	9.68	4.97

This indicates that practically all the water soluble polysaccharides are inulides, and that the inulin content is low, which is in harmony with the work of WILLAMAN (12).

### Preliminary analyses, 1926-27

The preliminary work was done on the crop of 1926. One variety of white girasole was grown in St. Louis County. Another lot of tubers, of an unknown variety, was secured from Portland, Oregon, and grown at University Farm; and some of the same variety, which had been grown at Portland, were sent to us in October and placed in a root cellar. Some French Mammoth were also grown at University Farm. Samples of tubers were dug at intervals during the winter and spring, some being analyzed immediately and others kept in a root cellar for various periods. The data are presented in table I.

It will be noted that the fructose content is rather low in comparison with that found by JACKSON, SILSBEE and PROFFITT (4). This is probably due to immaturity. The sample from Portland, Oregon, contains nearly twice as much fructose as the others.

During the winter, whether the tubers are in the ground or in storage, the fructose-glucose ratio is rather low. By May the ratio has increased

**TABLE I**  
**COMPOSITION OF GIRASOLE TUBERS, CROP OF 1926**

DATE DUG	STORAGE	FRUCTOSE		GLUCOSE*		FRUCTOSE PLUS GLUCOSE		FRUCTOSE GLUCOSE
		IN TUBERS	IN EXTRACT- ABLE DRY MATTER	IN TUBERS	IN EXTRACT- ABLE DRY MATTER	IN TUBERS	IN EXTRACT- ABLE DRY MATTER	
October	10 weeks in root cellar	Grown in St. Louis County, Minnesota						
	"	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	2.71
	"	10.08	3.72	13.80		13.80		1.62
	"	7.66	4.75	12.41		12.41		1.76
	"	8.42	4.78	13.20		13.20		1.69
	"	8.72	5.14	13.86		13.86		1.81
October	15 weeks in root cellar	8.24	4.56	13.31		13.31		1.40
	16 weeks in root cellar	7.91	5.65	13.56		13.56		
	5 months in sand in root cellar	Variety grown at Portland, Oregon						1.86
		15.47	8.28	23.75		23.75		
		Variety from Portland, Oregon, grown at University Farm						
	freshly dug	7.91	5.07	12.98		12.98		1.56
February 23	freshly dug	7.88	5.30	13.18		13.18		1.48
March 12	6 weeks in root cellar	7.20	41.8	4.94	28.7	12.14	70.5	1.46
" 12	3 weeks in root cellar	7.06	5.66	12.72		12.72		1.25
" 30	freshly dug	7.56	5.09	12.65		12.65		1.48
April 9	freshly dug	5.64	35.2	5.38	33.6	11.02	68.8	1.04
" 18	freshly dug	6.34	32.5	3.32	17.0	9.66	49.5	1.91
" 29	freshly dug	6.23	39.2	1.80	11.3	8.03	50.5	3.46
May 25	freshly dug							
February 23	1 week in root cellar	French Mammoth, grown at University Farm						
	1 week in root cellar	10.30	4.37	14.67		14.67		2.35
	freshly dug	8.02	4.27	12.29		12.29		1.88
	freshly dug	8.45	4.49	12.94		12.94		1.88
	freshly dug	7.84	5.50	13.34		13.34		1.43
	4 weeks in root cellar	7.23	42.4	4.87	28.6	12.10	71.0	1.48
April 9	freshly dug	6.73	38.8	2.86	16.5	9.59	55.3	2.35
May 10	freshly dug	6.33	41.9	2.00	13.2	8.33	55.1	3.16
" 25	freshly dug							

\* Glucose here means reducing sugars other than fructose in the hydrolyzed extract.

markedly. It must be pointed out that direct comparison may not be made between these 1926 samples and those grown in 1927.

### Experiments in 1927-28

The Portland variety of girasole was grown at University Farm in 1927 in sandy loam and in silt loam. They were analyzed when freshly dug on August 30, when the tubers were still immature; on November 3, when they had apparently gained their maximum development; and on December 20, January 30, and March 22, during the storage period. On November 3, some of the tubers on the sandy loam were dug and placed in three types of storage. The conditions of storage and the behavior of the tubers under these conditions is shown in table II and figure 1. The results of the analyses are shown in table III and in figures 2, 3, and 4.

TABLE II

PER CENT. OF SOUND, SHRIVELED AND DISEASED GIRASOLE TUBERS, UNDER DIFFERENT STORAGE CONDITIONS. GROWN AT UNIVERSITY FARM, ST. PAUL, MINNESOTA

STORAGE CONDITIONS		DATE OF INSPECTION	CONDITION OF TUBERS EXPRESSED IN PER CENT. OF ORIGINAL NUMBERS		
TEMPERATURE	RELATIVE HUMIDITY		SOUND	SHRIVELED	DISEASED
	<i>per cent.</i>		<i>per cent.</i>	<i>per cent.</i>	<i>per cent.</i>
Common storage 34-49.5° F.	73.9-86.1	January 30, 1928	27.7	38.7**	33.5
		March 29, 1928	7.5	6.9**	85.5
Common storage 33.5-44° F.	89.3-92.0	January 30, 1928	48.6	33.3**	18.0
		March 29, 1928	47.3	44.6**	19.3
Cold storage 32-35° F. ....	89.1-92.0	January 30, 1928	85.2	10.0*	4.7
		March 29, 1928	80.5	14.1*	5.2

\* Slightly shriveled.

\*\* Much shriveled.

*Condition of tubers.*—The data in the table indicate that the higher temperatures and lower humidities induce the shrivelling of the tubers as well as the attack by pathogenic organisms. On the other hand, the tubers keep very well at lower temperatures and higher humidities. Under the most favorable conditions supplied in these experiments (32°-35° F., and 89-92 per cent. humidity) 80 per cent. of the tubers were sound at the end of the period, less than 15 per cent. were slightly shrivelled, and 5 per cent. were diseased. Under the least favorable conditions (34°-49° F. and 74-86 per cent. humidity) only 7 per cent. remained sound, 6 per cent. were shrivelled and 85 per cent. were diseased.

TABLE III

SEASONAL VARIATION IN MOISTURE, DRY MATTER, FRUCTOSE AND TOTAL WATER SOLUBLE CARBOHYDRATES IN GIRASOLE TUBERS, PORTLAND VARIETY, IN THE GROUND AND IN STORAGE. GROWN AT UNIVERSITY FARM, ST. PAUL, MINNESOTA

STORAGE CONDITIONS	GREEN WEIGHT BASIS					DRY WEIGHT BASIS			RATIOS			
	DATE	MOISTURE	DRY MATTER	FRUCTOSE	GLUCOSE	TOTAL SUGAR	FRUCTOSE	GLUCOSE	TOTAL SUGAR	FRUCTOSE	FRUCTOSE	
										“GLUCOSE”	TOTAL	
Freshly dug tubers	Aug. 30	per cent. 84.6	per cent. 15.3	per cent. 6.7	I. Tubers grown on sandy loam			per cent. 43.6	per cent. 23.4	per cent. 67.1	1.86	0.65
	Nov. 3	79.8	20.1	9.9	3.6	10.3	49.5	25.0	74.6	1.97	0.65	
	Dec. 20	81.5	18.4	6.3	5.7	12.1	34.5	31.1	65.6	1.11	0.52	
	Jan. 30	81.2	18.7	6.5	6.3	12.8	34.7	33.7	68.5	1.03	0.51	
	Mar. 22	83.4	16.5	6.0	5.1	11.1	36.6	30.8	67.4	1.19	0.54	
Tubers stored at 32°-35° F. Relative humidity 89-92 .....	Dec. 20	78.7	21.2	7.9	5.7	13.6	37.4	26.9	64.3	1.39	0.58	
	Jan. 30	77.6	22.3	8.0	7.0	15.1	36.0	31.7	67.8	1.14	0.53	
	Mar. 22	76.2	23.7	8.5	6.1	14.7	36.0	26.0	62.0	1.39	0.58	
Tubers stored at 33°-44° F. Relative humidity 89-92 .....	Dec. 20	78.0	21.9	8.0	5.9	13.9	36.8	26.9	63.7	1.37	0.58	
	Jan. 30	77.9	22.0	8.2	7.3	15.5	37.2	33.1	70.4	1.12	0.53	
	Mar. 22	76.7	23.2	8.9	5.7	14.6	38.4	24.4	62.9	1.57	0.61	
Tubers stored at 34°-49° F. Relative humidity 74-86 .....	Dec. 20	76.8	23.1	8.5	5.6	14.1	36.9	24.2	61.1	1.52	0.60	
	Jan. 30	74.2	25.7	9.3	7.7	17.0	36.4	29.9	66.4	1.22	0.55	
	Mar. 22	69.0	30.9	10.5	7.6	18.2	34.1	24.7	58.9	1.38	0.58	
Freshly dug tubers	Aug. 30	83.4	16.5	8.5	II. Tubers grown on silt loam			51.8	21.3	73.2	2.42	0.71
	Nov. 10	78.6	21.3	10.9	3.5	12.0	50.9	26.7	77.6	1.91	0.65	
	Dec. 20	80.3	19.6	7.9	5.1	13.0	40.2	26.0	66.3	1.55	0.61	
	Jan. 30	82.3	17.7	6.7	5.9	12.7	38.0	33.7	71.8	1.12	0.53	
	Mar. 22	82.3	17.6	6.4	5.0	11.4	36.1	28.4	64.6	1.27	0.56	

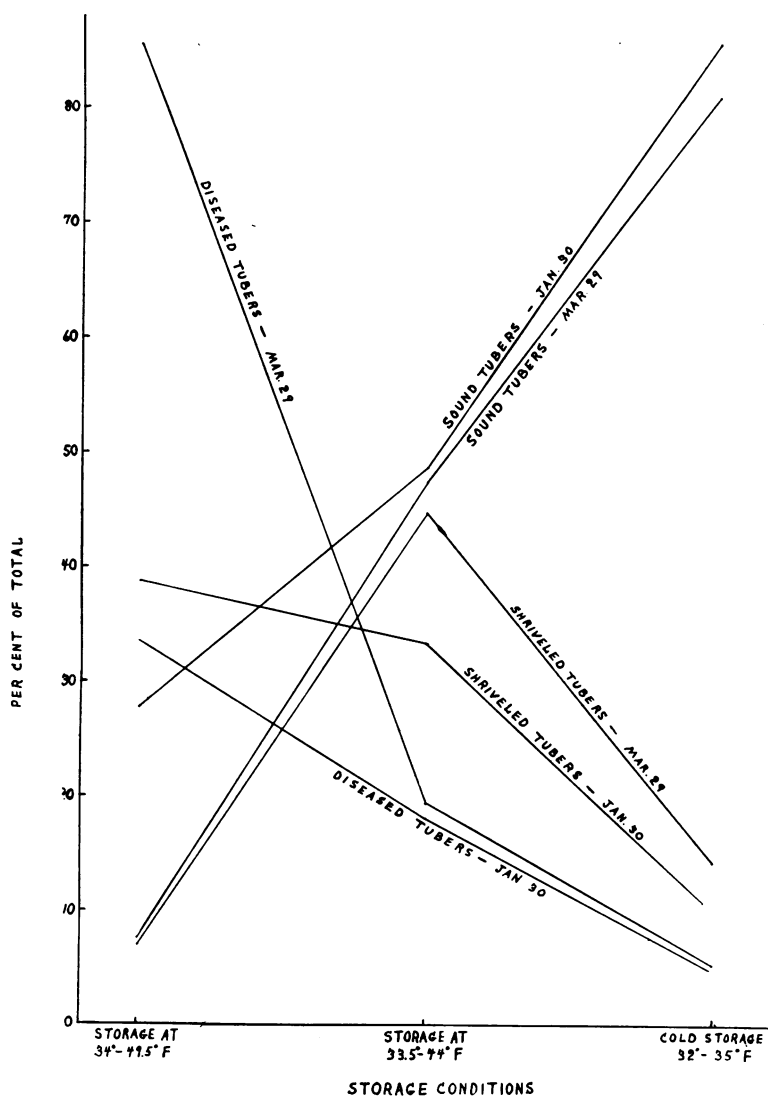


FIG. 1. Per cent. sound, shriveled, and diseased girasole tubers stored under various conditions.

*Moisture content.*—Prior to the storage period, November 3, there was an increase in dry matter, as shown in figure 2. From then until March 22, the tubers kept in the ground showed a steady increase in moisture. Those kept in a root-cellar at 34°-49° F. and relative humidity of 74-86 per cent. showed a consistent decrease in moisture, totaling 10.8 per cent. Those stored at 33°-44° F. and 89-92 per cent. humidity lost only 3.1 per cent., and those at 32°-35° F. and 89-92 per cent. humidity lost 3.5 per cent.

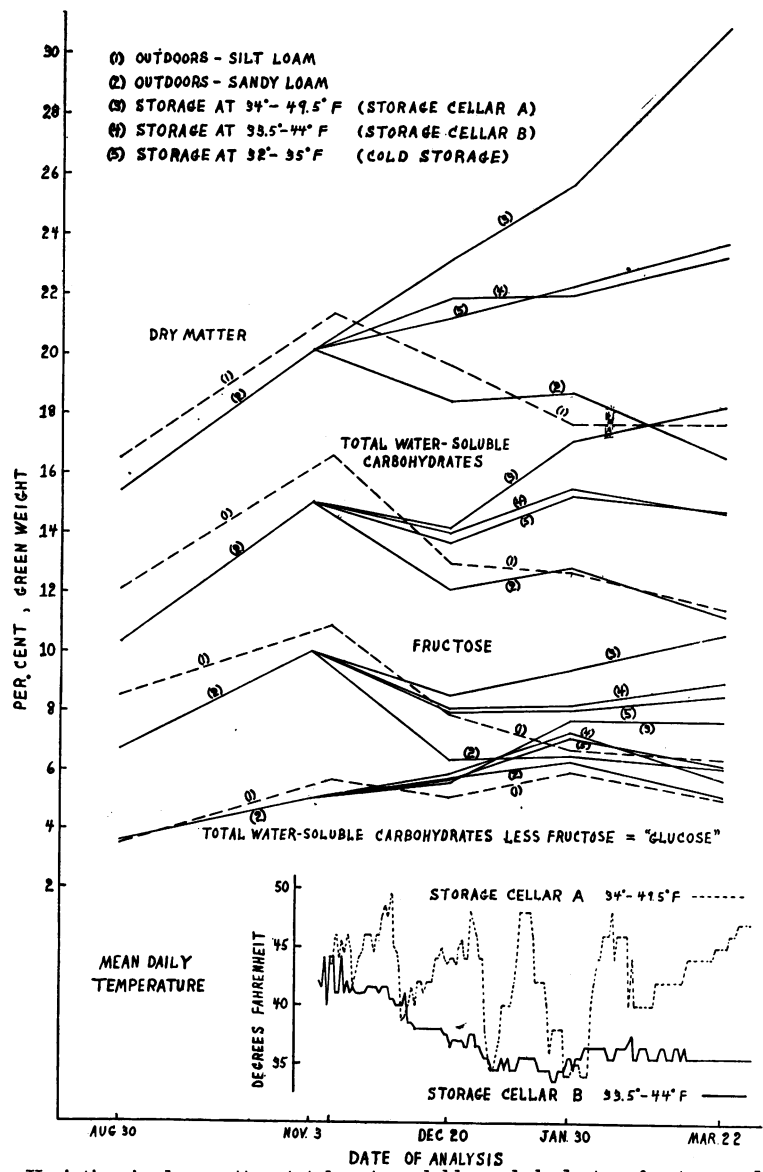


FIG. 2. Variation in dry matter, total water-soluble carbohydrates, fructose and "glucose" in girasole tubers under various storage conditions. University Farm, St. Paul, Minnesota.

*Carbohydrates.*—The total water-soluble carbohydrates are built up in the tuber until November, when a maximum is reached, both on the green and dry weight basis. This is shown in table III, and figures 2 and 3.

From November to March there is a total decrease in water-soluble carbohydrate on a dry weight basis. Between November 3 and March 22, there is a loss of more than 10 per cent. of the water-soluble carbohydrates on a dry weight basis. There are minor fluctuations which cannot be explained by the data presented. The rise in water-soluble carbohydrates on January

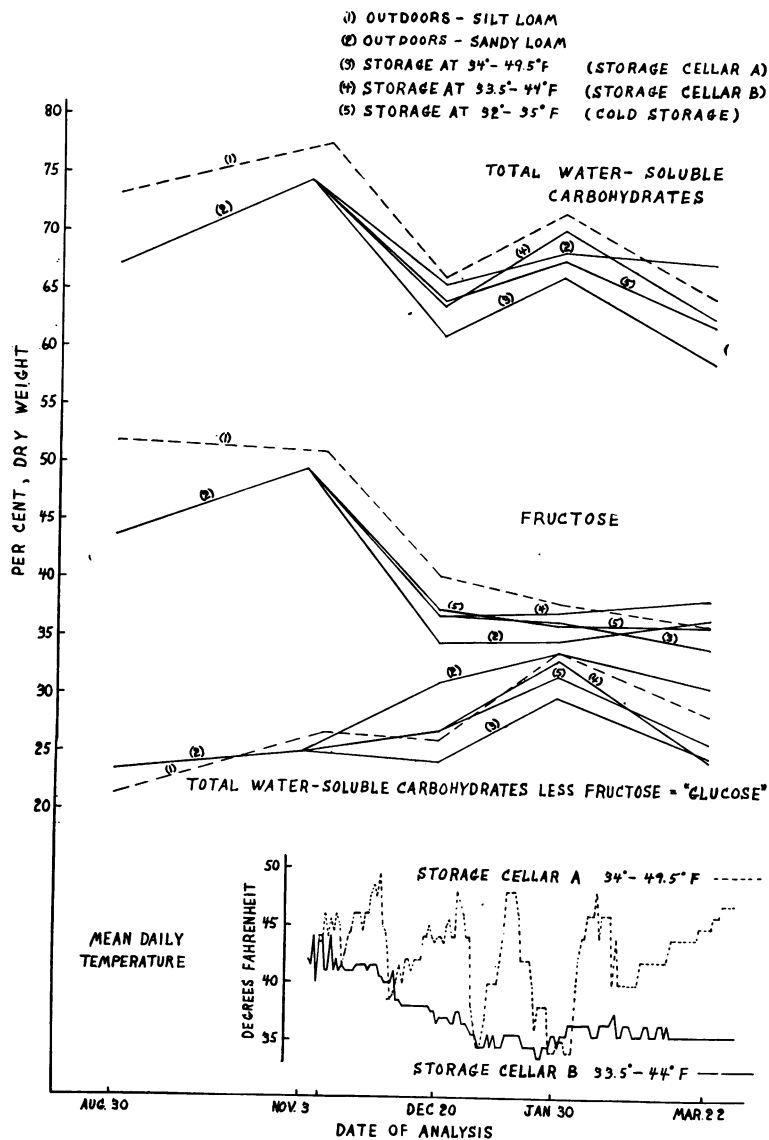


FIG. 3. Variation in total water-soluble carbohydrates, fructose and "glucose" in girasole tubers under various storage conditions.

30 may be due to the seasonal difference in the material. TRAUB (11) has shown that there is a difference in the carbohydrate fractions extractable from apple wood at various seasons of the year. It will be noted that the decline in fructose is consistent, and that the fluctuations in water-soluble carbohydrates is due to other unexplained causes.

In storage the continual loss of moisture apparently has a marked effect upon the percentage of total sugars per unit green weight, as shown in fig. 3. Under the more favorable storage conditions the moisture content and percentage total sugars per unit green weight are more constant.

From the standpoint of possible fructose manufacture the ratios of fructose to other sugars, and fructose to total sugars are of primary importance. During the winter, both in storage and in the field, there is a simultaneous increase in "glucose" and decrease in fructose, although the latter process is the greater as shown in figures 3 and 4. The total sugar content reaches a maximum at the beginning of November, and consequently the best time

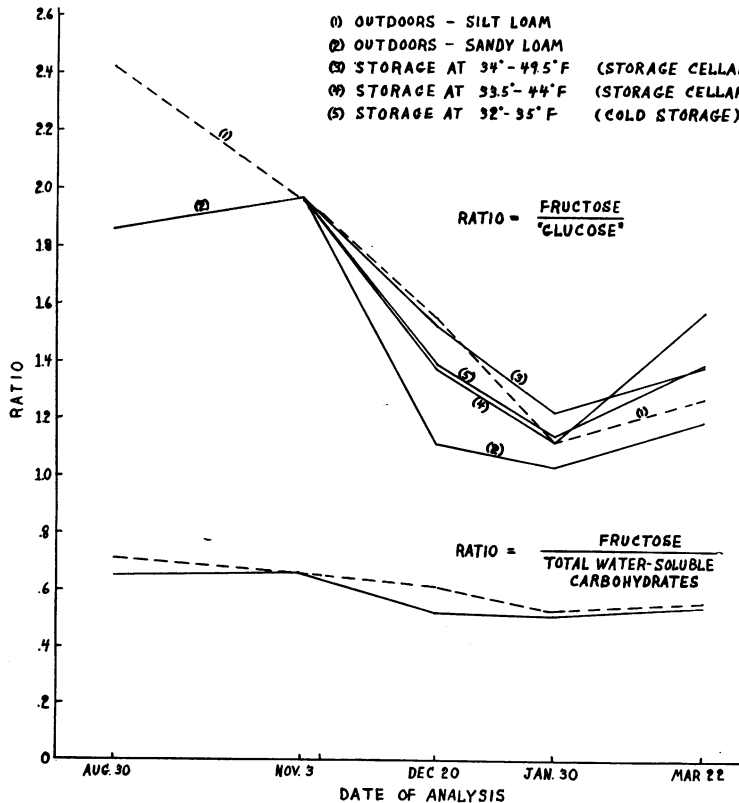


FIG. 4. Ratios of fructose to "glucose" and fructose to total water-soluble carbohydrates, in girasole tubers under various storage conditions.

to utilize the tubers for the maximum fructose yield per unit weight is at this stage when the ratio of fructose to other sugars is the highest.

### Conclusions

1. Girasole tubers in storage under the conditions of the experiment have a larger amount of water-soluble carbohydrates per unit green weight than tubers left in the ground over winter.

2. Girasole tubers may be successfully stored as a truck crop, and as propagation stock, at a temperature range of 32°–35° F., and a relative humidity of 89–92 per cent. The optimum conditions for storage, which may or may not approximate the conditions described above, are still to be determined.

3. Tubers stored at temperatures above 40° F. lose moisture rapidly, shrivel, and are subject to storage diseases to such an extent that practically the entire crop so stored is lost by the end of the storage period.

4. From the time of maturity in the fall up to the end of January there is a consistent decrease in the ratio of fructose to glucose, and of fructose to total water-soluble carbohydrates under all conditions studied. From the standpoint of possible fructose manufacture, harvesting and utilization should take place near the time of maturity in November under Minnesota conditions.

5. There is apparently a seasonal variation in the proportion of the water-soluble carbohydrates extractable.

6. Girasole tubers at the time of harvest do not contain appreciable amounts of free reducing sugars.

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